NUCLEAR ENERGY RESEARCH INITIATIVE

Use of Solid Hydride Fuel for Improved Long-Life LWR Core Designs

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Collaborators: Massachusetts Institute of Technology; Westinghouse Savannah River Company; University of Tokyo

Proposal Number: 2002-189

The general objective of this proposal is to assess the feasibility of improving the performance of PWR and BWR cores by using solid hydride fuels or solid hydride inserts. The concentration of hydrogen in the hydride fuel is comparable to that of hydrogen in liquid water of LWR cores. The introduction of part of the hydrogen needed for neutron moderation within the fuel volume permits attainment of optimal neutron spectrum while using a relatively small water volume fraction-just that amount of water that is required for comfortably safe cooling of the fuel. This feature enables the core to be designed to have optimal moderation, in terms of the attainable discharge burn-up, and to have a smaller volume or higher total power than a LWR core that uses oxide fuel. Moreover, thorium hydride fuel, one of the hydride materials to be examined, has a higher heavy metal (HM) density than oxide fuel. As a result of this higher HM concentration and larger fuel-to-water volume ratio, $U\text{-}ThH_2$ or $Pu\text{-}ThH_2$ fueled cores can be designed to have a significantly higher energy generation per core loading and significantly longer core life than the corresponding oxide-fueled cores. Preliminary estimates indicate that both the energy per fuel loading and core life could increase by more than a factor of 2. The core power level can also be significantly increased. The net outcome is expected to be improved economics, improved resource utilization, reduced waste, improved proliferation resistance, and improved safety.

This study may lead to the development of new fuel and core designs for LWRs that could have one or a combination of the following advantages relative to contemporary LWRs and those under development:

(a) Reduced capital cost by virtue of compaction and/or increased power output;

(b) increased discharge burn-up;

(c) increased core-life;

(d) increased energy generation per fuel loading;

(e) reduced fuel cycle cost;

(f) reduced waste volume and toxicity due to higher discharge burn-up and to partial utilization of Th;

(g) increased utilization of Pu relative to MOX fueled cores due to the higher discharge burn-up possible with hydride fueled cores of acceptable power density;

(h) utilization of thorium fuel resources;

(i) simplified design of BWR fuel assemblies and control systems along with improved stability against power oscillations;

(j) improved safety due to the large negative temperature coefficient of reactivity of hydride fuel;

(k) improved capability to dispose of plutonium in LWRs by using fertile-free PuH_2 or Pu-Zr hydride fuel; (the large prompt negative temperature coefficient of reactivity of hydride fuel may compensate for the lack of large negative Doppler reactivity effect due to absence of fertile fuel); and

(l) improved proliferation resistance due to enhanced destruction of Pu and use of thorium.

One hydride fuel being considered is uranium-zirconium hydride, similar to that developed by General Atomics (GA) for TRIGA reactors. This fuel has been in use for more than 40 years in many reactors around the world, both in constant power and pulsed power operating conditions. It has been extensively studied, and tested in reactors, and it has an impressive record of safety. Fuel for high power TRIGA reactors has been operating under conditions that in many aspects meet or exceed LWR fuel performance requirements. Relative to UO_2 fuel in LWRs, this TRIGA fuel operates at close to twice the average linear-heat-rate, and reaches more than twice the discharge burn-up. The thermal conductivity of the TRIGA fuel is nearly six times larger than that of UO_2 so that its peak fuel temperature under typical LWR operating conditions is estimated to be below 700°C, which is acceptable and provides a comfortable margin. Some of the novel core designs with hydride fuel being proposed will feature lower linear heat rate and hence, lower peak fuel temperatures. This will result in a large margin to accommodate transients that lead to fuel temperature increase. Uranium-zirconium hydride fuel was also used in a sodium-cooled SNAP space power reactor developed by Atomics International.

Another hydride fuel proposed for consideration is uranium-thorium hydride. It was proposed as fuel for nuclear reactors by the late Dr. Masoud Simnad, the developer of the TRIGA fuel. $U\text{-}ThH_2$ is even more stable than U-ZrH1.6 fuel and can operate at higher temperatures. More importantly, the HM density in the $U\text{-}ThH_2$ fuel can exceed the U density in UO_2. It is estimated that by using U-ThH2, it is possible to load more than twice the amount of HM into a core of a given volume than in the corresponding well- moderated UO_2 (or MOX) fueled core. This implies that it might be possible to extend the time between refueling by more than a factor of two, or, in principle, double the core power level.

Prof. M. Yamawaki of the University of Tokyo has recently developed and tested a U-Th-Zr-H fuel and carried-out performance tests including in-core irradiation. The maximum permissible linear heat rate limit of that hydride fuel is estimated to be 500 w/cm, more than is needed for economic LWR operation. Prof. Yamawaki will collaborate on this study and provide needed data. Before passing away several months ago, Dr. Simnad had also expressed great interest in participating in this proposed project.

Another, smaller part of the study will assess the feasibility of designing PWR and BWR cores to have long life and large discharge burn-up using very compact lattices incorporating small amount of non-fuel containing solid hydride. The function of the solid hydride is to limit the spectrum hardening upon 100 percent voiding of the water coolant, and thereby help achieve a negative void coefficient.

The study will address primarily reactor physics, and thermal-hydraulic, safety, fuel-cycle, and economic considerations. Material compatibility research will be undertaken as a follow-on study provided the conclusions from the present study justify doing so. To ensure that the present study will adequately take into account material-compatibility issues, two material specialists, Prof. Olander of the University of California at Berkeley, and Prof. Yamawaki of the University of Tokyo, an expert on hydride fuels, have been included on the team.
A complete list of the collaborators, their institutions, and their areas of expertise follows:

(1) Greenspan , University of California at Berkeley, neutronics

(2) Olander, University of California at Berkeley, material compatibility

(3) Todreas, Massachusetts Institute of Technology, thermo-hydraulics and safety

(4) Petrovic and Garkisch, Westinghouse, practical fuel and core design considerations and economics

(5) Yamawaki, University of Tokyo, hydride properties and compatibility

The funding for Prof. Yamawaki's involvement will be provided by Japanese sources.